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Analysis

Support for Emissions Reductions Based on Immediate and Long-term Pollution Exposure in China

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ABSTRACT

Reducing power sector emissions in China is a critical step toward mitigating climate change and lowering health damages from air pollution. We conduct a discrete choice survey (N = 1060) among urban residents from 10 Chinese cities, assessing how individuals compare electricity source, cost, and reduction of emissions related to climate change or air pollution. Using observed air quality data, we also evaluate how pollution levels affect respondents' support for different types of emissions reductions. We find that reductions targeting both climate change and human health benefits have stronger support than those which address only one of the two. Furthermore, respondents in cities with the highest annual concentrations of particulate matter are willing to pay 30% more to clean up the air when compared to individuals living in less polluted cities. The analysis suggests that the public values co-optimizing mitigation policy across climate and health objectives, and that making available information on long-term air quality may encourage sustained support for cleaner energy.

1. Introduction

China's rapid economic development has been fueled by an equally swift increase in energy consumption. Thus far, the electricity portion of this rising demand has largely been supplied by coal-fired power plants, with coal providing close to 75% of electricity generation in 2014 (China Electric Power Press, 2016). As a result, the Chinese power sector produces substantial emissions, which in turn have important implications for local and regional air quality as well as global climate change.

A major effect of power sector emissions on air quality comes from the contribution of these emissions to concentrations of $PM_{2.5}$ (particulate matter with aerodynamic diameter ≤ 2.5 μm). Exposure to $PM_{2.5}$ is strongly linked with premature mortality and other adverse health effects (Pope et al., 2002; Pope and Dockery, 2006). Recent air quality studies find that the population weighted concentration of $PM_{2.5}$ in China is 52 μg/m^3, far exceeding the World Health Organization Air Quality Guideline of 10 μg/m^3 (Rohde and Muller, 2015; Zhang and Cao, 2015). These studies also estimate that elevated $PM_{2.5}$ was responsible for 900,000 to 1.2 million deaths in 2013, making it the 5th largest risk factor for mortality in China (Rohde and Muller, 2015; Zheng et al., 2017). Although dispersed emitters, such as vehicles and home heating, are responsible for most of the $PM_{2.5}$, coal combustion for electric power generation alone is estimated to cause over 86,000 deaths per year, approximately 10% of all deaths linked to elevated $PM_{2.5}$ (GBD MAPS Working Group, 2016). Most of this impact comes from the formation of secondary $PM_{2.5}$ from emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x); depending on the season, secondary $PM_{2.5}$ formed from sulfate, nitrate, and ammonium is responsible for as much as 50–60% of total $PM_{2.5}$ mass (GBD MAPS Working Group, 2016; Yang et al., 2013; Zhang et al., 2012). Over one quarter of the country's total SO_2 emitted in 2012 came from electricity generation, making SO_2 from the power sector an important influence on air quality and human health in China (MEIC Team, 2015; Nielsen and Ho, 2007).

In addition to concerns over air quality, China's emissions from electricity generation also pose a substantial threat in terms of accelerating climate change. In 2005, China became the largest emitter of carbon dioxide (CO_2) on an absolute emissions basis, and with 10.4 Gt of CO_2 emitted in 2015 it is responsible for approximately 29% of global CO_2 emissions (Le Quéré et al., 2016). As of 2014, coal-fired power plants were responsible for 30% of Chinese CO_2 emissions (China Electric Power Press, 2016; Kahrl et al., 2011; MEIC Team, 2015). Although China has committed to peaking CO_2 emissions by 2030 and to increasing the use of non-fossil energy sources, the current dominance

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of coal in the power sector suggests the challenge of achieving these goals and of advancing policies for dramatic CO_2 reductions.

Despite the fact that the government has pledged to tackle the problems of climate change and air pollution, the Chinese public has become increasingly concerned with the poor air quality and vocal in their support of curbing emissions. Recent research has sought to quantify this support through stated preference or choice-based surveys instruments, and a range of studies have found that individuals largely have a positive willingness-to-pay (WTP) for renewable energy or for strategies that reduce emissions (Chen et al., 2016; Guo et al., 2014; Li et al., 2015; Tang and Zhang, 2016; Wang and Mullahy, 2006; Zhang and Wu, 2012). While these studies have explored support for improving air quality, mitigating climate change, or deploying green energy more generally, one unaddressed question is how individuals weigh improvements to climate and health in their support for emissions reductions, and how they make tradeoffs between these two attributes. While several "no-regrets" policies that address both climate and health are available in China, a fuller understanding of public support for addressing these two impacts may be increasingly important in cases where options for tackling both are limited or where the costs and benefits of different strategies may vary widely (Aunan et al., 2003, 2004; Gielen and Changhong, 2001; Vennemo et al., 2006). Eliciting detailed preferences on climate and health tradeoffs can thus serve as input to more effective policies for integrated emissions reductions.

Although the growing pressure from the Chinese public for clean energy has largely been attributed to high levels of pollution, the precise relationship between air quality and support for emissions reductions has not been extensively explored and is a promising area of research. While it might be intuitive to expect individuals to base their preferences for emissions reductions on long-term air quality trends, research in social and behavioral science suggests that individuals often utilize heuristics that tend to overemphasize recent or extreme events when expressing beliefs or values (Kahneman, 2000). For example, Zaval et al. find that respondents who perceived temperature abnormalities on the day of a survey indicated higher levels of belief in global warming (Zaval et al., 2014). Previous work in China has also found that exposure to haze and perceptions of low visibility during the course of a survey are related to pro-environmental attitudes and higher WTP for improved air quality (Tang and Zhang, 2016; Yu et al., 2015). If individuals only pay attention to recent air pollution levels, long-term support for emissions cuts may be hard to sustain in the face of highly variable levels of public interest. However, if individuals pay attention to their long-term exposure to pollution, then support for mitigation can be maintained by making those exposure levels easily accessible and comprehensible.

In this work, we employ a discrete choice survey to explore how respondents make tradeoffs between climate and health emissions reductions, electricity bills, and the mix of sources of energy that are used to produce electricity. Discrete choice surveys consist of providing respondents with a series of hypothetical alternatives—each described by a combination of defining characteristics or attributes—and then observing the choices they make between those alternatives (Hanley et al., 1998; Kjær, 2005; Louviere, 2006; Vossler et al., 2016). Such choice experiments have been increasingly used to assess preferences in energy and the environment, including some focused on China (Aravena et al., 2014; Bergmann et al., 2006; Byun and Lee, 2017; Helveston et al., 2015; Kaenzig et al., 2013; Longo et al., 2008; Min et al., 2014; Sergi et al., 2018). In addition, we test how respondents' valuations of the tradeoffs between climate, health, and cost are related to $PM_{2.5}$ concentrations at different time scales. We assess respondents' valuation of these tradeoffs by implementing this survey across 10 Chinese cities ($N = 1060$). Our analysis thus seeks to answer the following research questions:

1. How do individuals value **tradeoffs** across climate change, air quality, the cost of electricity, and the energy sources used to produce electricity?
2. Do immediate or historical levels of experienced **air pollution** affect preferences for health- or climate-related emissions reductions?

While previous research has explored discrete choice studies on energy preferences in China, we believe ours is the first to assess respondents' tradeoffs between the climate and health benefits of emissions reductions. In addition, our work is novel by including observed air quality levels and evaluating their link to respondents' preferences. Using our survey results, we evaluate our research questions by modeling both individuals' probability of support and their WTP for different combinations of changes to emissions and electricity generation portfolios.

2. Methods

In this section, we explain the design of the survey instrument, the sampling method used to collect responses, and the methods used to analyze the results.

2.1. Survey Design

In the discrete choice task of the survey, respondents face 16 two-alternative choice scenarios and are asked to indicate which of the two alternatives they would prefer for their provincial government to pursue. Each alternative is characterized by four attributes, described as follows.

1. **Electricity portfolio** — the mix of sources used to produce electricity, conveyed as a bar graph displaying the percentage share of generation coming from thermal power (coal), nuclear energy, hydroelectric dams, and renewable sources (specified as wind and solar).
2. **Change in monthly electricity bill** — economic cost to the consumer, conveyed as a percentage change to the price of their electricity bill relative to the amount that they currently pay.
3. **Change in annual CO_2 emissions** — the change in annual CO_2 emissions relative to current levels in their province, described to respondents as "climate change related emissions" and presented with a number line.
4. **Change in annual SO_2 emissions** — the change in annual SO_2 emissions relative to current levels in their province, described to respondents as "health related air pollution" and presented with a number line.

Each of these four attributes can take one of five possible levels, and different combinations of the attribute levels are used to construct the various alternatives shown in each choice scenario. An example screenshot of one of these choice scenarios is provided in Fig. 1, while a table of the attribute levels and a description of how those levels were chosen can be found in Section A of the Supplementary Information (SI).

We select these four attributes based on a desire to explore people's tradeoffs between the cost, climate, and health implications of energy technologies. For climate, the choice of CO_2 is intuitive given that it is the leading greenhouse gas from the power sector. For health, we focus on emissions of SO_2 based on their role as precursors to $PM_{2.5}$. As discussed in the introduction, most of the negative health consequences from particulate matter come from secondary $PM_{2.5}$ (i.e., $PM_{2.5}$ formed from other pollutants, namely SO_2) rather than directly emitted (primary) $PM_{2.5}$. As an illustration, a source-apportionment study in the U.S. found that around 49% of the power sector's contribution to ambient $PM_{2.5}$ concentration came from sulfate alone (Caiazzo et al., 2013). While this fraction is likely different for China, the use of

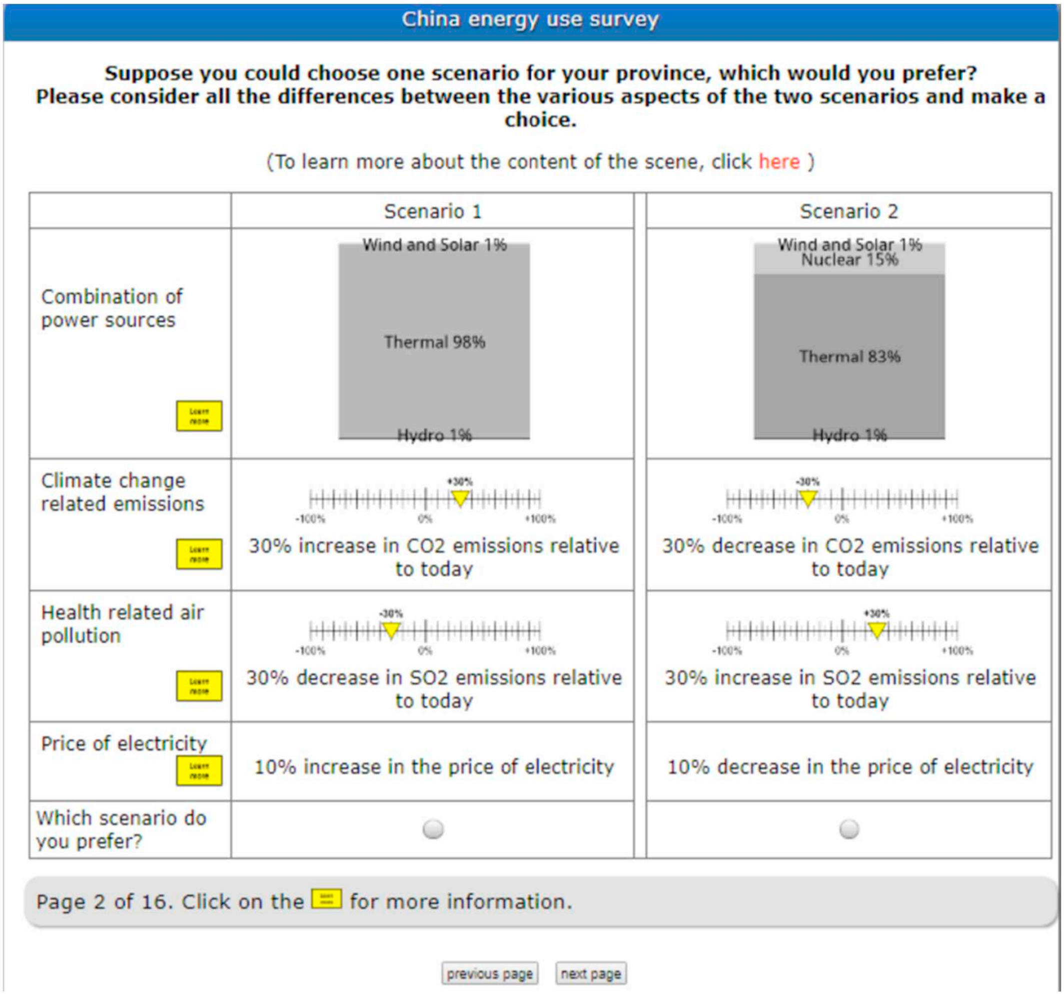

Fig. 1. Example choice screen for a respondent from Beijing, translated into English. Respondents completed the survey in Chinese, and a Chinese-language version of a comparable choice is provided in SI Section A.

relatively high sulfur coal along with the slow adoption of flue gas desulphurization on older plants suggests it would not be substantially lower. Similarly, one study in Northern China estimated that secondary particulate matter accounts for 55% of total particulate matter mass (GBD MAPS Working Group, 2016; Yang et al., 2013). Based on this, we use CO_2 as our proxy for climate-related emissions and SO_2 as our proxy for health-related emissions.

With four attributes and five possible levels for each attribute, there are 625 unique alternatives and 195,000 choice combinations. Each respondent in our survey sees a unique, semi-random subset drawn from the full factorial of two-alternative choice combinations. We design the survey using Sawtooth Software's Lighthouse Studio,[1] which generates a design intended to balance main effects estimation with level overlap for interactions. Of the 16 choices that we present respondents, 10 of those choices were generated semi-randomly by the software. The remaining six choices are given fixed levels and are used to test whether respondents are paying attention to the task and whether their choices are consistent with transitive and linear preferences.

Discrete choice surveys typically include a status quo option as one of the alternatives in the choice set, as previous work suggests that including this as an option can improve internal consistency in respondent decision-making (Hanley et al., 2002). Because the attributes in our choice experiment are themselves defined relative to a baseline level, however, we did not include this status quo in every choice, although some choices do include a scenario with all attributes at baseline levels. While a status quo option is important for modeling preferences for goods that a consumer can choose not to purchase, we argue that the choosing between two policy options is a realistic way to consider possible changes to electricity sector policy while minimizing the cognitive burden of the task.

When beginning the survey, respondents are first provided with information on the task, after which they are asked to sign a consent form to participate and to indicate the province where they live. To provide respondents a sense of consequentiality—which research has shown can improve the external validity of choice surveys—they are informed that their responses will be used to guide national energy policy recommendations from Peking University's research team (Vossler et al., 2016). In the following section, respondents are provided a visual mock-up of the discrete choice experiment and information on the attributes provided in the task, including on the effects of CO_2 and SO_2 emissions on climate and health. Respondents are then asked to answer two questions about the material they read to test their understanding and comprehension, after which they proceed to the discrete choice task. Following the 16 choices in the tasks, respondents rate the importance of each attribute as a measure of construct validity and are asked several follow-up questions. These questions evaluate their understanding of the relationships between CO_2 and climate and SO_2 and health, assess general environmental attitudes and support for emissions reductions, and collect basic demographic information.

[1] See Sawtooth webpage: https://www.sawtoothsoftware.com/.

2.2. Sampling and Demographics

We administered our survey to 1060 individuals across 10 different cities in China between January and May 2017, with approximately 100 respondents per city. These 10 cities were chosen to diversify representation from different regions of China (coastal, northeast, central, and west; see SI Section B for a map of the sampled cities). Because we sample only from urban areas and neglect rural populations, the results from our survey are not generally representative of China. Other studies have found that urban Chinese express more concern over air pollution and environmental damage, and have larger WTP for emissions reductions relative to rural populations (Li et al., 2015; Yu, 2014).

Respondents were recruited to the survey in-person in public forums, such as parks, malls, and public squares. Recruitment and administration of the survey were facilitated by representatives from a professional survey company who were trained by the research team. All survey participants were at least 18 years of age. The surveys were conducted on a tablet with a survey administrator present. Respondents were compensated with a small gift for their participation. The average survey completion time was approximately 15 min, with 75% of respondents completing the survey in > 11 min.

Summary demographic statistics by city and for the total sample are presented in SI Section B. The breakdown of respondents by gender and age is relatively comparable across the different sampling cities. The total fraction of males in our survey is slightly lower than that of China overall (51% in 2014) while the median age of our sample (37 years) is slightly older than that of the country as a whole (approximately 35 years) (National Bureau of Statistics of China, 2015). There is more variability in sampling across the cities in terms of educational attainment and annual household income. For example, our sample includes high shares of individuals having a college or advanced degree in Beijing, Guangzhou, Shanghai, and Urumqi. For income, 42% of respondents had household income < 80,000 RMB; as a reference, the average urban household income in China in 2015 was approximately 90,000 RMB. In general, we are slightly biased toward high-income individuals—although this in part driven by the fact that Beijing, Guangzhou, and Shanghai are relatively wealthy cities—which limits the applicability of our results to Chinese urban residents more broadly.

2.3. Statistical Analysis

Individuals' responses to the discrete choice experiment are evaluated using an additively separable, mixed logit random utility model. In this model, utility U for individual i is a function of the attributes in choice j and an unobserved error component (ε_{ij}), which we assume to be random draws from a Type I Extreme Value distribution (Train, 2009). Eq. (1) depicts the form of this model, where each instance of β represents a modeled coefficient for the corresponding attribute variable X; a description of the model variables can be found in SI Section C.

$$\begin{aligned} \mathrm{U}_{ij}(X) = {} & \beta_{REN}X_j^{REN} + \beta_{NUC}X_j^{NUC} + \beta_{HYD}X_j^{HYD} + \beta_{BAL}X_j^{BAL} + \beta_{BILL}X_j^{BILL} \\ & + \beta_{CO2,i}X_j^{CO2} + \beta_{CO2^2}(X_j^{CO2})^2 + \beta_{SO2}X_j^{SO2} + \beta_{SO2^2}(X_j^{SO2})^2 \\ & + (\beta_{PM,CO2}X_j^{CO2} + \beta_{PM,SO2}X_j^{SO2}) * PM_{i,t} + \varepsilon_{ij} \end{aligned} \tag{1}$$

The mixed logit specification allows for heterogeneity in preferences across individuals; we estimate these random effects for the bill and emissions attributes under the assumption that preference variations follow a normal distribution. In addition to modeling linear effects for each attribute, we also model a semi-quadratic term for each emissions term to allow for diminishing marginal returns to emissions reductions. To ensure that our assumption about the additive nature other model is reasonable, we also test models with interactions between emissions and bill levels. While we find some significant estimates, the effect sizes are small and do not influence the results (see SI Section C for details).

To estimate the effect of air quality on respondents' preferences, we model an interaction between actual air quality levels and the attribute levels of CO_2 and SO_2. We test various temporal specifications of air quality—including $PM_{2.5}$ concentration for the respondent on the day of the survey, the average $PM_{2.5}$ concentration the month prior to the respondent taking the survey, the average annual concentration in 2015 and 2016, and the worst "peak" concentration in the same two years—to evaluate whether the interaction is sensitive to different time scales. $PM_{2.5}$ concentration data was obtained by scraping a website that reports Chinese government air quality monitoring data for hundreds of cities across the country.[2] Summary statistics of the $PM_{2.5}$ concentration data are available in SI Section D.

To interpret the model in terms of preferences for different attribute tradeoffs, we use the logit coefficients to estimate the probability that an average respondent would support various combinations of attribute levels. The probability of support for any given attribute combination is derived from the modeled utility function using the following relationship:

$$Prob = \frac{1}{1 + e^{-V(x)}} \tag{2}$$

where $V(x) = \vec{\beta} \cdot \vec{X}$ is the average individual's observed utility function, or the total utility from Eq. (1) above, less the unobserved error term. The conditional probability of a scenario thus represents the likelihood that an average respondent will prefer that scenario's combination of attributes over the status quo, with all other attributes held at baseline levels. Since this is a two-alternative choice scenario, the utility function represents utility for differences in attribute levels between the two scenarios. By evaluating the probability of support for different combinations of portfolios and changes to monthly electricity bills and emissions, we can gain insight into respondents' preferences for tradeoffs across those attributes. Results in the main text are provided for respondents' preferences relative to the current baseline (i.e. the status quo).

In addition to probability of support, we can compute willingness-to-pay (WTP) as a measure of individuals' tradeoffs between economic cost and changes to other attributes (Train and Weeks, 2005). In this case, economic cost is represented by the change in monthly electricity bills. WTP for any combination of attributes and non-linear terms (or willingness-to-accept, in the case of negative values) can be calculated by solving for the change in monthly bill such that observed utility $V(x) = 0$, meaning that the respondent is indifferent between that combination of attributes and the current, baseline scenario. This calculation is shown in Eq. (3), where $\vec{\beta'} \cdot \vec{X'}$ represents observed utility from all attributes except electricity bill. This calculation assumes that respondents would not reduce their electricity demand in response to higher electricity prices; if that were the case, our calculation would underestimate respondents' true WTP (see SI Section E for further discussion).

$$WTP = -\frac{\vec{\beta'} \cdot \vec{X'}}{\beta^{BILL}} \tag{3}$$

3. Results

3.1. Support for Improving Health and Mitigating Climate Change

Fig. 2 illustrates the likelihood that an average respondent would support alternative energy portfolios that increase different energy sources (renewables, hydro, or nuclear) relative to current baseline, which for most provinces is largely coal. The figure shows results for scenarios where the alternative energy portfolios are 20% more expensive than the baseline but yield different changes to emissions (see

[2] Data source: http://www.tianqihoubao.com/aqi/.

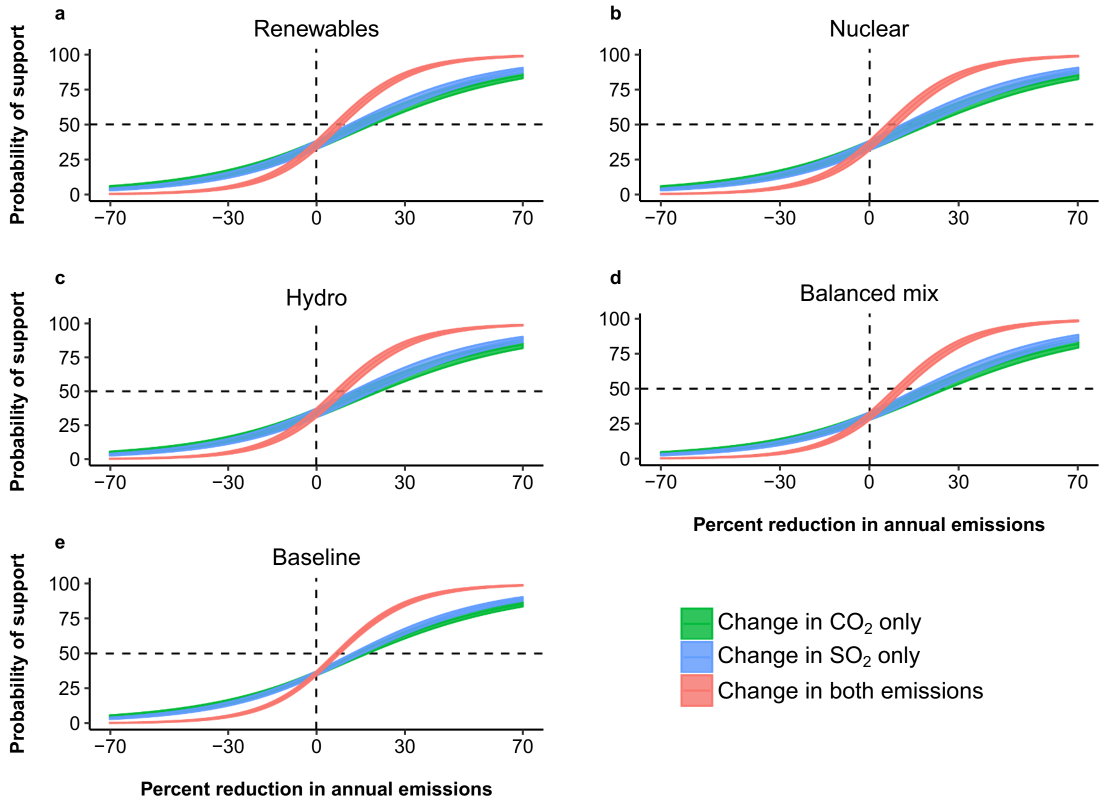

Fig. 2. Probability of support of an average respondent for various combinations of changes to emissions (in percent change from baseline, shown on the x-axis), and alternative portfolios (shown in each panel). Results shown for alternative portfolios that include a 20% increase in monthly electricity bills. Probabilities are calculated relative to the baseline reference portfolio (i.e. the current energy mix of the respondent's province) with no changes to bills or emissions. Results for alternative portfolios with no increased cost are shown in SI Section E. Descriptions of the alterative portfolio levels can be found in SI Section A.

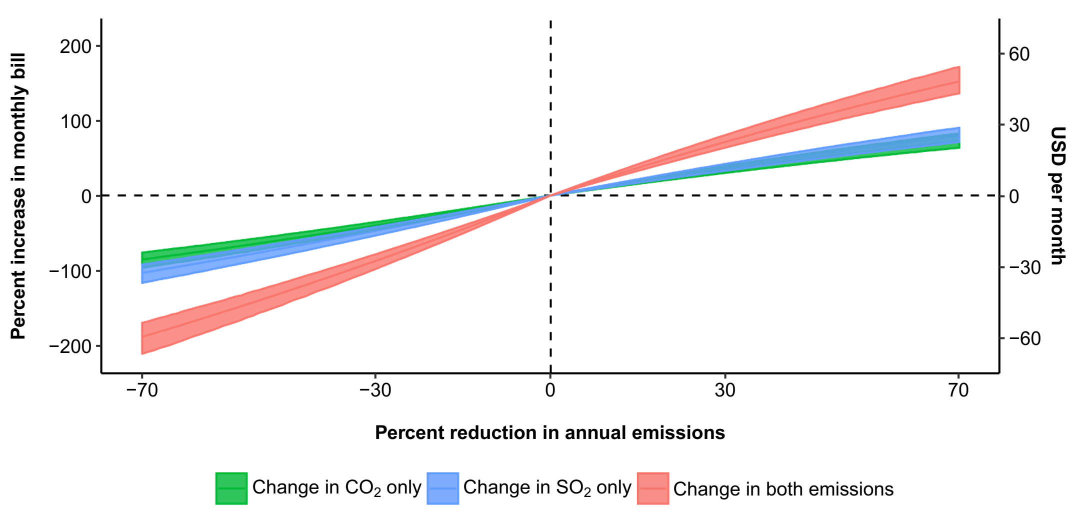

Fig. 3. WTP for reductions in emissions of CO_2 and SO_2 (negative x-axis indicates emissions increases). Results are shown in terms of percentage increase in monthly bills as well as USD equivalent using respondents' self-reported monthly electricity bills (sample average of approximately $30 USD per month after adjusting for purchasing power parity). See SI Section E for full WTP model and discussion.

SI Section C for regression coefficients and Section E for results with no change to electricity bills).

The figure indicates that with increased bills and no changes to emissions, the average respondent prefers to keep the current provincial electricity mix over one that increases renewable, nuclear, hydro or a mix of those (referred to as the "balanced" portfolio). This suggests that the average respondent does not prefer to pay for these alternatives without their emissions benefits. If the alternative portfolio offers sufficient reductions in CO_2 or SO_2 emissions, however, then respondents prefer the alternative to the baseline even with 20% higher bills. For respondents to be indifferent between their current electricity mix and an alternative with 20% more expensive electricity bills, the alternative portfolio would need to provide roughly 16% reductions in CO_2 (95% confidence interval (CI): 13–18%), 14% reduction in SO_2 (95% CI: 12–16%), or 7% reductions in both pollutants simultaneously (95% CI: 6–8%).

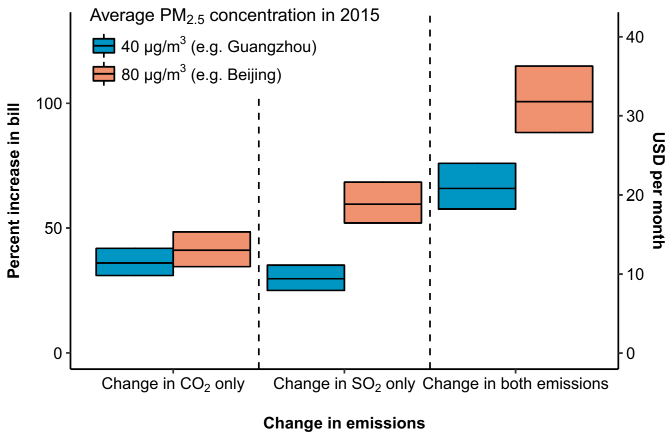

Fig. 4. WTP (as percentage increase in monthly electricity bill and in USD) based on interaction between average $PM_{2.5}$ in 2015 and preferences for emissions reductions. WTP is estimated for respondents living in the least and most polluted cities in our sample, which in 2015 had annual concentrations of 40 and 80 μm/m^3, respectively.

Overall, we find that the average respondent is not very sensitive to the type of portfolio (e.g. coal, renewables, hydro, or nuclear), instead focusing on the accompanying emissions reductions and cost. The importance of attributes over source type is consistent with other surveys on energy preferences (Ansolabehere and Konisky, 2014). An exception to this rule is that respondents tend to be slightly averse to the "balanced" portfolio, in which 15% of coal is replaced by an equal share of hydro, nuclear, and renewables. While more investigation is needed to understand this preference, one possible explanation for this is that respondents may perceive greater risk in pursuing multiple technologies at once. Understanding this preference is potentially relevant given China's current pursuit of an "all of the above" energy strategy. In addition, we observe no statistical difference between preferences for reducing health-related air pollution (SO_2) relative to emissions that cause climate change (CO_2) — the average respondent places comparable importance on both types of emissions.

Another way to explore respondents' support for different portfolios and emissions cuts is to assess their willingness to trade increased costs for gains in those attributes. Fig. 3 shows the WTP of an average respondent for different combinations of reductions to CO_2 or SO_2, both in terms of percent increase in monthly bills and U.S. dollar (USD) equivalent based on respondents' self-reported electricity bills after adjusting for purchasing power parity. The figure highlights how respondents are willing to pay more if both pollutants are reduced simultaneously. For example, the estimated WTP for a 30% reduction in CO_2 or SO_2 alone is $12–13 USD (95% CI: $9–13), while WTP for reducing both pollutants is approximately $23 USD per month (95% CI: $20–25), or approximately 80 Chinese yuan (RMB). These WTP results over the course of a year would amount to about 0.7–1.7% of the average national annual household income (National Bureau of Statistics of China, 2016). As a source of comparison, a previous study found Chinese households were willing to pay an average of 40 RMB per month for a scenario including 11–20% reductions of CO_2 and improvements to air quality and acid rain, roughly consistent with our findings for addressing a single pollutant (Zhao et al., 2017).

We also find that respondents demand more in compensation for emissions increases relative to what they would pay for emissions reductions, behavior that is consistent with reference dependent preferences and Prospect Theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992). For example, our model estimates that respondents would be willing to pay 71% more in electricity bills for a 30% reduction in both CO_2 and SO_2 (95% CI: 64–81%), but would demand 87% in lower bills as compensation for an increase of the same amount for both pollutants (95% CI: 78–98%).

Another metric that can be useful for policy-makers and individuals interested in pricing externalities is the WTP per ton of emissions reduced. Combining our modeled estimates for WTP with respondents' self-reported electricity bills, an estimate of the number of households in China, and 2012 estimates of emissions of CO_2 and SO_2 from the power sector, we calculate the implied WTP per ton for a 30% reduction in annual emissions (MEIC Team, 2015; National Bureau of Statistics of China, 2015). After adjusting for purchasing power parity, we find that respondents' choices are consistent with a WTP of around $60 per ton of CO_2 and $36,000 per ton of SO_2 reduced (95% CI of $56–72 and $32,000–40,000, respectively). For comparison, recent work on the social cost of carbon has estimated that climate change damages incurred by China are on the order of $24 per ton CO_2 ($4–50, 66% CI) (Ricke et al., 2018). While estimates of the marginal damages of SO_2 in China are scarce, other studies have found ranges of $8000–24,000 in Europe and an average value around $35,000 for the U.S. (Fann et al., 2012; Holland et al., 2005).

3.2. The Influence of Air Quality on Preferences for Emissions Reductions

To understand whether observed air quality affects respondents' preferences, we test the effect of an interaction term between actual observed $PM_{2.5}$ concentration and preferences for CO_2 and SO_2 changes, using the various timescales described in the methods section. Results from the mixed logit regression with these various interaction coefficients are presented in SI Section C.

We find that the day-of and prior month $PM_{2.5}$ concentrations have a small and non-significant effect on respondents' preferences for emissions reductions. Although a stronger trend in the daily effect might be masked by variability in $PM_{2.5}$ concentration within a city (which we do not observe), we also test the daily model using a more spatially granular air quality index (AQI) recorded at the site of the survey and find similar results. However, we do find a strong relationship between the average annual concentration of $PM_{2.5}$ and respondents' preferences for reductions in SO_2, and this relationship seems to be stronger with the 2015 $PM_{2.5}$ average than with the 2016 average. There is also an association between larger peak events and stronger preferences for CO_2 and SO_2 reductions, and this effect is also slightly stronger for the 2015 average than for 2016.

Using the model with annual $PM_{2.5}$ concentration from 2015, Fig. 4 provides an illustration of how the average respondent's WTP for emissions changes varies based on their $PM_{2.5}$ exposure. The average respondent's WTP for a 30% reduction in SO_2 increases from 30% (95% CI: 25–35%) to 60% (95% CI: 52–68%) when comparing respondents exposed to the lowest $PM_{2.5}$ concentration in 2015 (e.g. Guangzhou) with those exposed to the highest concentration (e.g. Beijing). While there is little difference in WTP for CO_2 emissions across different pollution levels, the difference in preferences for SO_2 is substantial enough to carry over to increased levels of support for reductions in both pollutants.

The link between annual average $PM_{2.5}$ and support for emissions cuts is primarily driven by four cities—Beijing, Harbin, Chengdu, and Urumqi—which have the highest pollution levels and where respondents have strongest preferences for emissions reductions. Of the cities in our sample, these are also locations where the issue of air quality is at the forefront of public discussion. Beijing, Harbin, and Chengdu all experienced orange or red alerts for air pollution between December 2016 and March 2017, and a large public protest occurred in Chengdu in late 2016. Individuals in these cities were also the most likely to indicate in our survey that they perceived air quality was deteriorating, with over 80% of respondents in Harbin and Chengdu saying that pollution was getting worse or much worse in recent years, compared to around 20% of respondents in Shanghai, Lanzhou, and Guangzhou (see SI Section B). Thus, respondents may be able to resist certain biases in decision making, such as being overly influenced by recent events (Kahneman, 2000), because of the longevity and salience

of the air quality issue in these cities and the subsequent importance of the issue in the public discourse.

Because respondents in the same city share the same annual average $PM_{2.5}$ concentration, our findings on the effect of $PM_{2.5}$ may be confounded by other city-level differences. We assess a model including these city-level effects, variables for respondents' self-reported incomes, and an interaction with daily $PM_{2.5}$ concentrations to parse out whether the air quality effect is being driven by other inter-city differences. We find our daily $PM_{2.5}$ effect estimate remains undiminished by including these variables, suggesting that our findings are not masking pure city-level heterogeneity or income levels (see SI Section C for details on these checks).

3.3. Respondent Heterogeneity and Consistency Checks

The results so far describe effects and preferences estimated for the average respondent. We also collected demographic information to see if any variations in preferences might be associated with different individual characteristics, such as income or education level. In addition to the city-level heterogeneity for emissions preferences discussed above, we observe that respondents with higher income and education levels place less importance on increases in electricity bills, which in turn gives them higher willingness-to-pay for emissions reductions (see SI Sections C, E, and F for further discussion).

We also include in our survey a series of checks to assess whether respondents understand the task and are providing internally consistent responses. These include questions to assess whether respondents can distinguish between the effects of SO_2 and CO_2; dominated alternatives designed to evaluate whether respondents are paying attention; and a series of choices testing for transitive and linear preferences. Respondents performed well on these understanding and consistency checks, suggesting that they understood the task, are aware of the distinction between the climate and health effects of the two types of emissions, and are making internally consistent choices. Details on these checks are provided in SI Section G.

4. Discussion and Conclusions

We find that respondents from the 10 Chinese cities we sample have strong preferences for emissions reductions, and that support increases dramatically if both climate- and health-related emissions are reduced, even if these emissions cuts imply relatively large increases in monthly electricity bills. Respondents do not demonstrate strong preferences for different sources of electricity, suggesting that the attributes of electricity generation—such as emissions and costs—are more important than the actual mix itself. This result may be biased by the fact that we exclusively sample from urban populations, which are largely removed from the sources of electricity generation. Nevertheless, this finding is consistent with other studies of energy preferences in the U.S. (Ansolabehere and Konisky, 2014) and suggests the need for policies that evaluate energy technologies based on their ability to achieve environmental and economic objectives.

An exception to respondents' openness to different technologies is that their choices are consistent with a weak disutility for scenarios that replace coal with multiple sources of clean energy. While this may reflect on people's skepticism for pursuing an "all-of-the-above" strategy—as opposed to pursuing economies of scale with one or two technologies—it may also be indicative of the fact that large changes to one technology in the survey are more salient to respondents. Although more research is needed to understand this pattern, it highlights the importance of understanding public preferences when developing and advancing the use of different technologies to meet the country's energy transition needs.

We observe a relationship between long-term and peak $PM_{2.5}$ concentrations and preferences for emissions reductions, but no strong relationship at daily or monthly timescales. This result suggests that respondents are relying on long-term air quality trends when evaluating the importance of emissions reductions, and may be less affected by day-to-day changes. The salience of long-term air quality in key cities where preferences are strongest suggests that public awareness of and access to consistent information on historical air quality may play an important role in developing sustained support for emissions reductions. The average respondent in the survey has a WTP around 38–42% more in monthly electricity bills for 30% reductions in either CO_2 or SO_2 (around $12–13 USD), and close to 80% more for simultaneous reductions in both emissions ($23 USD). Accounting for the interaction with annual $PM_{2.5}$ concentration, we find that respondents in the most polluted cities are willing to pay 30 percentage points more in monthly electricity bills for a 30% reduction in SO_2 relative to respondents in the least polluted cities.

Based on these results, respondents do seem to favor strategies that address both air pollution and climate-related emissions, such as transitioning away from coal-fired power, over strategies that only address air quality, such as installing flue-gas desulfurization. By pursuing interventions that consider both types of emissions, China is likely to gain additional public support for its energy transition. However, the extent to which poor air quality induces additional support for climate action may be limited, and China's most polluted regions may be able to capture more public support for immediate air pollution interventions even while there is support for long-term emissions reductions to address climate change. This variation in preferences suggests that in addition to national efforts to transition to a low carbon energy sector—such as the creation of CO_2 cap and trade systems and funding for carbon-free energy deployment and research—highly polluted regions may benefit from and more strongly support targeted, immediate air pollution control policies relative to long-term strategies.

Our findings suggest that China stands to benefit in terms of popular support by co-optimizing its emissions reductions strategies for both climate and health benefits. Furthermore, communicating both the climate and health benefits of emissions reductions is likely to increase support for those policies, particularly in areas with a history of poor air quality. Increasing awareness of historical pollution levels by providing consistent and reliable data may also help cement further support by increasing the salience of long-term air quality trends. Although the applicability of our results to China more broadly is somewhat limited because we sample only from urban areas, our results suggest that communication efforts can help build support among the Chinese public for strategies to reduce emissions.

Declaration of Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2018.12.009.

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